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Analysis of Smoke Hazard in Train Compartment Fire Accidents Base on FDS

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Abstract

Train compartment is very special confined spaces; fire smoke in compartment brings great hazards when fire broke out. It is the main reason which caused people to die or hurt. This paper uses CFD method based on the FDS. It analyzes the main features of fire smoke on the human body injury; simulate smoke flow caused by compartment fire; It computes and analyses the interior fire smoke's diffusion process, the cabin space area of smoke concentration distribution and the temperature distribution and trends, and discusses and analyses the impact of smoke and temperature change in the train personnel in emergency evacuation.

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Keywords: numerical simulation; train fire; smoke hazard; FDS

1. Preface

The personnel density in a train of high speed being so high and the room being limited that once it fired, it can spread quickly, which will undoubtedly cause an inestimable damage. The fire would produce poisonous and irritating gas such as CO, Hydrogen cyanide due to the storage of mass new type of polymer composite materials, fiber-reinforced plastics (FRP), polyurethane (PUR) included. And in a short period of time, it will release plenty heat of combustion and to form dense smoke mixed with high temperature combustible gas which flows rapidly. It's likely to lead to the further spread of the fire. If no action taken to stop the fire and smoke spread, people in the train would be in great danger What's more, the limited compartment space, personnel density and the suburban location of the running train led to the difficulty of fire fighting and evacuation[1]. Consequently, it's helpful for us to prevent and fight with fire and do an evacuation if we study on the generation mechanism and flowing feature of smoke and the law of temperature distribution.

This paper simulates the flow of smoke in compartment fire using large eddy simulation method of CFD base on FDS and PyroSim2010. They are studied the feature of the spreading process of smoke and the fire, and the variation trend of the temperature field. The effect of the smoke and fire to the evacuation in emergency is also in our concern.

2. Harmfulness of smoke and Judgement of danger

The fire smoke causes casualties mainly due to the characteristics of its toxicity, high temperature and the light shielding[2-3].

(1)Toxicity of smoke

Toxicity of smoke is the main reason of casualties in a fire. According to the statistics of NFPA, every year, 2/3 to 3/4 death in fire due to inhalation of too much poisonous smoke, among which 60% to 80% people lost their lives in the place far away from the fire resource. Meanwhile, it's determined that the horizontal diffusion velocity of smoke cause by cross-ventilation in the beginning of fire is 0.3 m/s; and in the combustion violently stage, because of the heat convection a high-

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temperature state, the horizontal diffusion velocity of smoke will rise to 0.5~0.8m/s. It shows that the rapid spread of toxic gases in a fire caused a wider range of accidents.

Toxicity of smoke mainly comes from CO. CO after respiratory tract by inhalation through the alveoli into the blood circulation, combined with hemoglobin to form carboxyhemoglobin, which led to the hemoglobin lose the ability to carry oxygen. It mildly poisoned are dizziness, headache, Nausea, blurred vision and other symptoms; while severe poisoning patients have a cherry red skin, disturbance of consciousness, some fell into deep shock or even go into the cadaverous syncope state, die of lung failure or heart failure. It regained consciousness after severe patients in an emergency; there may be the sequelae of delayed encephalopathy symptoms. Generally, the critical concentration of CO is 2500 ppm in the space beneath the height of people's eyes. And the critical concentration of smoke is 2.08%. This text adopts the above values as the critical concentration.

(2)Smoke in high temperature

Human will get tired and dehydration in high temperature. When the heat exceeds the tolerance of human, they die.

Introduction to Building Fire Safety Engineering presents that, people can only bear several minutes when the temperature of air rises above 100℃. Generally speaking, nobody can breathe air hotter than 65℃. YU Bo (2006) adopted 1.5m as the average height of human's characteristic height. At this height, human is able to survive below or equal 80℃ and in danger even die above 80℃.

In consideration of the limit of compartment space and the density of personnel, the tolerable critical temperature should be lower. This text adopts 1. 5m as the characteristic height, critical temperature set as: 60℃ at the plane of 1.5m above the floor of train

(3)Light-shielding property of smoke

Smoke is the mixture of solid particle and liquid drop. Light was weakened as it went through the smoke. The light-weaken property of smoke determines the drop of visibility in a room filled with smoke, which is a great trouble of evacuation in a fire. Visibility refers to the maximum distance of the object can be seen by normal eyesight. According to *Code for Design of Metro* in China, people would be in danger when the visibility at the characteristic height is less than 10m. ZHANG Juan (2010) recommended that the tolerable visibility in the small space is 5 m or higher. This paper adopts 5m as the critical visibility.

3. Model establishment

3.1. Compartment geometry model

This paper established the train model using one compartment of SKE-2000 EMUs as the prototype. The size of compartment is 25m ×3.9m ×2.6m (length * width * height). There are 20 seats on each side of the carriage, and it has a seating capacity of 100 people. 10 air conditionings are arranged on both sides at the top of the compartment, adopting ventilation method which air supply on top and using door return in the end of compartment at the same time. The train internal physical model has been simplified when simulating, ignoring the compartment of the external dimensions and internal components influence. The compartment geometry model was shown in Fig.1.

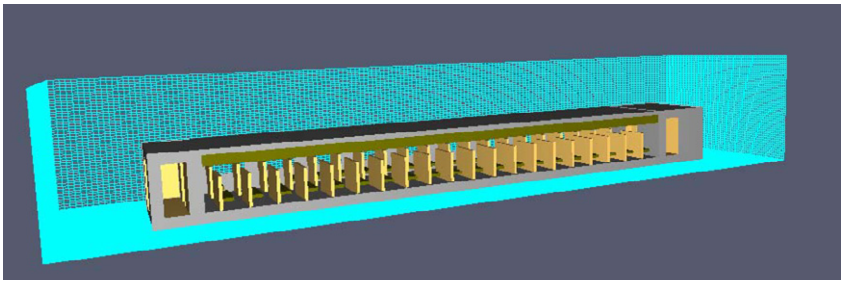

Fig. 1. The simplified compartment geometry model

3.2. Simulated condition

According to the different 0f the location of the fire, the initial conditions and boundary conditions, the fire condition will be divided into several categories as table 1 shown.

Table 1. the fire condition to simulate

Condition categorize		NO.	HRRPUA/ MW	RAMP-UP Time /s	Fire position
The location of the fire		Ⅰ	1.2	250	Middle seat
		Ⅱ	1.2	250	Middle luggage
		Ⅲ	1.2	250	Seat at the end
		Ⅳ	1.2	250	Luggage at the end
The doors and windows open or not	closed	Ⅴ	1.2	250	Middle seat
	Open when fire 100s later	Ⅵ	1.2	250	Middle seat
The compartment air conditioning open or not	open	Ⅶ	1.2	250	Middle seat
	closed	Ⅷ	1.2	250	Middle seat

4. Discussion of calculation parameters

4.1. Turbulence model selection

The eddy of large-size play a leading role in the turbulent flow field, small size eddy mainly causes the diffusion of the turbulent momentum. Turbulence numerical simulation model includes direct numerical simulation (DNS) turbulence model and non-direct numerical simulation turbulence model, in which non-direct numerical simulation model can be divided into Large Eddy Simulation (LES), the statistical average model and Reynolds Averaged Navier-Stokes model (RANS). The FDS provides two models to choose, which are LES and DNS. This paper adopts LES for the numerical simulation of train compartment fire. DNS is the perfect model, but it is not feasible in practical engineering because of current computer capacity. The RANS has low requirements for computing power, and are widely used in engineering. LES directly solves large-size eddy and solves small size eddy by simulating, the amount of computation and the accuracy is between DNS and RANS[4-5].

4.2. Fire source and air conditioning settings

Due to the complexity of the multi-component chemical combustion, most of the simulation software adopts a rapid chemical reaction model which is relatively simple to simplify the model. Adopted in this paper is the rapid chemical reaction model.

Using FDS to simulate the fire spread need to set fire ignition energy. Refer to the reference, fire source is set to t2 fire, and Ramp-Up Time are set to 250s. Heat Release Rates Per Area under different fire conditions were set to 0.6MW, 0.9MW and 1.2MW.

High-speed trains are equipped with air conditioner. There are 20 air conditioners lined up in two rows at the top compartment. The size of each air conditioner is 1.5m × 0.1m (length × width). Based on the thermal comfort, PMV-PPD index and passengers' living habits and wearing situation in the summer car with air conditioner, the air conditioner's wind speed is set to -0.15M / s in the Z-direction.

4.3. Domain mesh and the initial environment of simulating settings

This paper uses compartment's length, width and height as the coordinates X, Y, and Z direction, sets the computational domain is 31m × 8m × 5m, divided computational grid in the Cartesian coordinate system which number is 155 × 80 × 50. Assume that ambient temperature inside and outside is 20 ° C, pressure is 101325.0 Pa, and smoke concentration is 0 at the initial time. Calculating the time span is 1000s.

5. Analysis of simulation results

5.1. The simulation results of the different fire position

Depending on the different location of the fire inside the train compartments, this paper simulate Middle Seat (I), Middle Luggage (II), Seat at the end (III) and Luggage at the end (IV) fires respectively. Using case I as an example to analysis smoke hazard of compartment fire. In case I train's air conditioning does not turned on, compartment doors and windows open after the fire broke out 100s.

(1)High temperature. As shown in Fig 2.

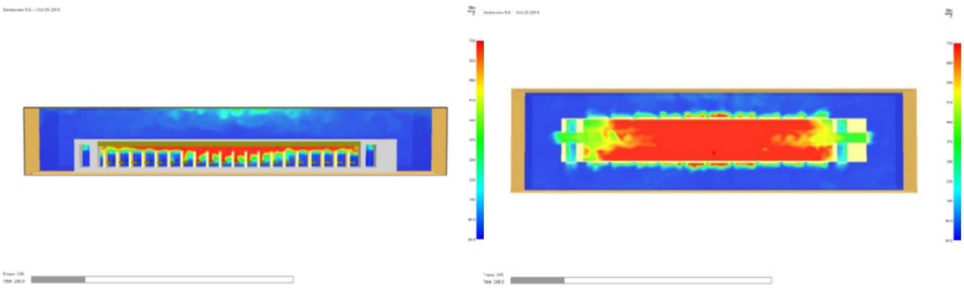

Fig. 2. when t=246 s, temperature distribution of Middle Seat fire.

The results show that the maximum temperature inside the compartment can reach 720 ° C. About 200s after the fire broke out, the plane of the height of human eye characteristics temperature begins to be higher than 60 ℃. The compartment comes into the dangerous critical state, began to threaten the safety of personnel inside, so the evacuation should be earlier than this moment.

(2)Smoke Spread. As Shown in Fig 3.

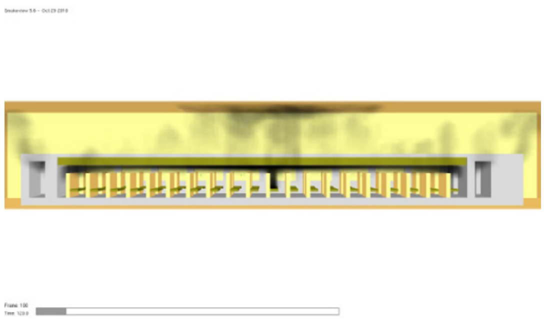

Fig. 3. In 120s smoke distribution if fire from central seat.

Fig 3 shows that after fire accidents of 120s, the smoke layer downs to the seat height and life would be threatened.

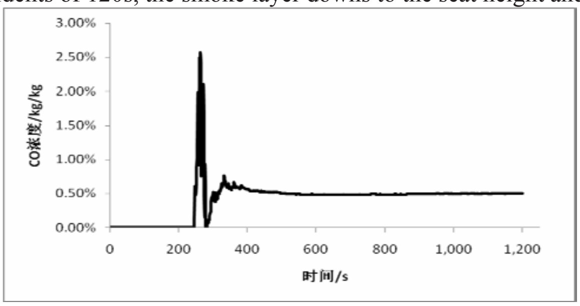

Fig. 4. CO concentration change of left door.

When simulate, this paper sets two CO monitor points in the left and right main exit. Figure 4 shows the CO concentration change of the left door. As you see in Fig 4 that in the primary developmental stage of fire, CO concentration keeps in zero. After the fire broke out 250s it begins to rise anomalously fast and can up to 30%. In a short time later, it will rapidly fall and will be stabilization at 5% at last. It can be concluded that after the fire occurred 250s, the CO concentration of most of the time more than a dangerous critical concentration 2500ppm, or 0.25 percent, threatening the safety of people in the train.

(3)Visibility. As shown in Fig 5.

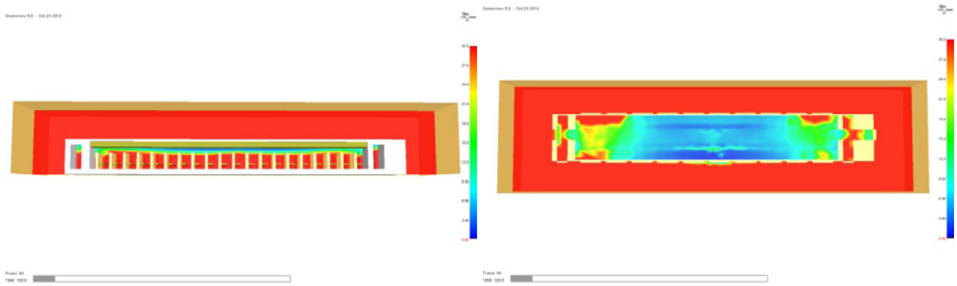

Fig. 5. Visibility spatial distribution if fire caused by central seat.

Seen from the simulation results, the visibility in the upper of compartment decreases rapidly after the fire broke out. When the time gets 100s, the visibility in the characteristics of the human eye height plane has most reached a dangerous critical state, down to 5m, security is threatened. When t= 255s, all space in compartment's visibility is close to zero.

5.2. The simulation result of doors and windows open or not.

In order to investigate how the compartment doors and windows open or not affect smoke spread in compartment fire, this paper simulates the two kinds of Middle Seat fire. Case V refers to in the entire process of fire, the carriage doors and windows are always closed. Case VI refers to when the fire broke out 100 s, the car broke down the windows to escape through the emergency hammer, and opened the door emergency, making the compartment doors and windows all open. Figure 6 shows that when t = 200s, the contrast of the condition V condition VI smoke spread.

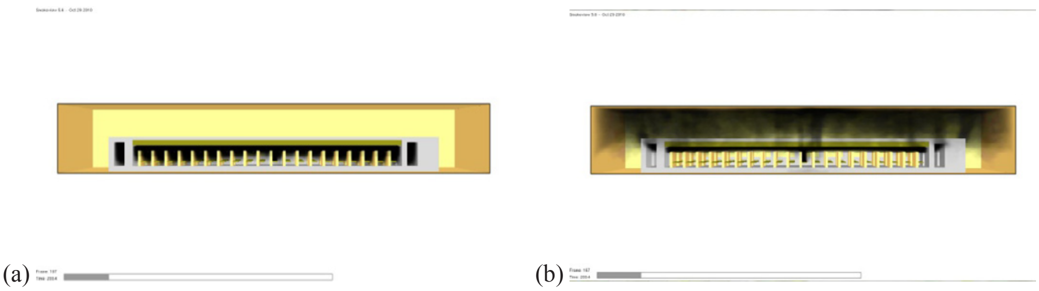

Fig. 6. Smoke spread in 200s contrast between (a) case V and (b) case VI.

As it can be seen from Figure 6, compartment doors and windows open situation significantly affect the rate of decline of the smoke layer. In case V, because the doors and windows closed, the smoke cannot spread to the outside of the compartment and its concentration grows fast. The CO stable concentration is 1.8% in case V, It is twice higher than 0.6% in case VI. And the smoke layer's settling velocity is faster than case VI, so it shortens the time of safe evacuation.

5.3. The simulation result about air conditions how to affect smoke spread.

In order to analyze air condition how to affect smoke spread in Middle Seat fire. We simulate case VII and VIII. In case VII air conditions are on operation and case VIII they are off.

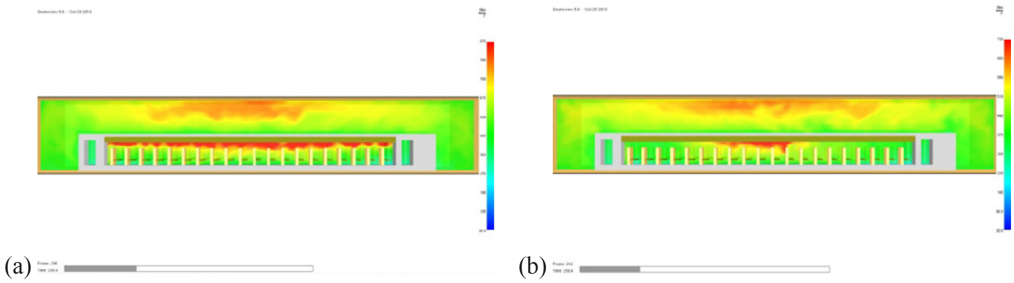

Fig. 7. Temperature distribution contrast between (a) case VII and (b) case VIII

Simulation results show that the opening and closing of the cabin air conditioning have a great impact on the compartment fire spread. As it can be seen from Figure 7 (a), the air conditioning opened promotes the flow of air, so that combustion is more intense and lasting. It brings a greater threat to personnel safety. The maximum temperature reached 870 ℃ in case VII. It is 150 ℃ higher than 720 ℃ which is the maximum temperature in the case VIII . And the highest heat release rate in case VIII is 110MW which is also lower than the highest rate in case VII that reached 120MW.

6. Conclusion

Smoke hazard is the main harm to passengers in the train compartment fire. Through simulate 1).fire is caused from different place;2).whether doors and windows are open;3).whether air conditions are on operate during fire and analyze the smoke spread and temperature distribution we can get these:

(1)Each condition we assume will jeopardize the safety of passengers in a short time in train compartment fire. Each simulation shows that in 100s to 200s, the temperature/CO concentration/visibility/smoke sinking will over critical state. Therefore we should evacuate passengers to safe area quickly.

(2)The doors and windows of Train compartment should easy to be opened. From case V and VI we know if the doors and windows are closed the smoke concentration rise and smoke sink rapidly.

(3)Air conditions will make fire to be worse. From case VII and VIII we get that if air conditions are on operate the temperature will rise more quickly and the heat release rate will be faster.

Acknowledgements

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